7/25/68

A DEVELOPMENT OF QUANTITATIVE INDICES FOR THE ASSESSMENT OF MANUAL PERFORMANCE DEFICIT OF BRAIN DAMAGED SUBJECTS

A THESIS

Presented to

The Faculty of the Graduate Division

by

Jackson Holt Birdsong

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

in the School of Industrial Engineering

Georgia Institute of Technology

May, 1969

A DEVELOPMENT OF QUANTITATIVE INDICES FOR THE ASSESSMENT OF MANUAL PERFORMANCE DEFICIT OF BRAIN DAMAGED SUBJECTS

Approved

Chairman

Date Approved by Chairman 5/30/69

ACKNOWLEDGMENTS

To each member of my committee goes my gratitude for his contributions in his own fashion. This could not have been possible without each.

Samuel B. Chyatte, M. D. will understand why I must include his name among my advisors. I also cannot ignore the contributions of everyone who would listen.

And to my never-complaining, understanding wife, Rachel, who contributed graciously from her personal wealth of understanding and her miniscule endowment--thanks.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

CHAPTER I

INTRODUCTION

Purpose of Investigation

The purpose of this investigation is to provide a means of assessing recovery from brain damage and the effects of treatment applied to brain damaged subjects. Motivation for this study arises from the realization of the limitations of assessments of motor character activity of the upper limb as employed by medical and paramedical personnel and the limitations of psychological evaluations of the effects of brain damage.

By employing appropriate Industrial Engineering techniques in conjunction with Medical and Paramedical techniques, a means of quantifying some effects of brain damage may be determined. Further, the natural history of recovery and the effects of therapy may be documented by numerical indices. The isolation, identification, and quantification of subunits of motor areas which do not require treatment or are not involved, or of those subunits requiring more intensive treatment may be achieved.

Medical Approach

A variety of approaches to the assessment of motor character activity are presently being used. First, the purely medical or neurological assessment is used to establish some gross parameters by which to judge the extent of motor character change, the degree of recovery, and the effect of treatment. Skilled judgments are made by the examiner of the motor power, agility, perceptual abilities, and intellectual function. These judgments are recorded along with a few objective measures, to be compared with judgments from similar but not necessarily duplicate examinations at another time.

Psychological Approach

A second approach to assessment is employed by the psychology discipline. Psychologists evaluate brain damaged patients with an assortment of tests, such as; intelligence tests, motor performance tests, perceptual-organizational tests, and others. Some of these tests achieve more objectivity by the use of timed, reproducible tasks, but motor performance is either not isolated from non-motor factors or the motor act itself is not subjected to sufficient scrutiny. For example, the Purdue Pegboard[1] test is a timed, reproducible system of testing which isolates motor performance to a reasonable degree from non-motor factors, but only grossly defines the motor act. The peg is picked up, moved, placed in a target hole, and a series of cycles is timed; but the process of picking up the peg, moving it, and placing it in the target hole is not individually examined.

Other Approaches

A third approach to assessment of brain damage and its effects on motor performance could be labeled as a "yes-or-no" technique of evaluation. Rehabilitation personnel gauge motor performance as related to Activities of Daily Living (ADL)[2]. The activities measured (eating, dressing, grooming, etc.) are dependent upon many non-motor functions and in addition are seldom timed. Since overall function, self-care, and self-dependence are the goals, most ADL activities are not required to be done in a specific fashion as long as they can be accomplished.

More sophisticated systems of testing such as the Thomasat[3] and the TOWER[4] systems test vocational abilities, many of which are not predominantly motor activities. The Thomasat test involves a variety of complex tasks which often isolate motor performance but the system does not evaluate the components of the motor performance differentially.

While the need for objective assessment of motor character activity resulting from brain damage and assessment of the results of treatment would seem obvious, it is of value to survey some of the major areas involved. Basically, most physicians and, to some extent, paramedical personnel dealing with a brain damaged individual must have some means of estimating the degree of change in motor character activity, the probability for recovery, and the degree of eventual recovery expected before proper management can be instituted. The various procedures previously mentioned all have value, but none provides detailed information concerning the motor performance character existing in the subunits of the affected motor areas.

Objectives of Investigation

The study of these subunits employing Industrial Engineering techniques can assist in providing evidence as to which components of motor performance have been impaired and which components recover spontaneously. The components which fail to recover may be evaluated for response to various treatment regimes, using Industrial Engineering techniques to supply quantitative comparisons of treatment efficacy.

An understanding of this portion of the problems resulting from brain damage leads into the following objectives and methodology for accomplishing these objectives:

To develop and examine a methodology which will:

1. Objectively quantify the degree of change of motor character activity in the upper extremity of victims of brain damage (cerebrovascular disease).
2. Quantitatively evaluate the degree of change of motor character activity in the subunits of the upper extremity of victims of brain damage (cerebrovascular disease).
3. Assist in the formulation of a concept of the degree of upper extremity motor performance improvement possible in the rehabilitation of victims of brain damage (cerebrovascular disease).
4. Design a means of practically arriving at the aforementioned objectives.

A successful methodology for accomplishing the objectives should have at least the following characteristics:

1. Recognized bodies of knowledge as sources.
2. No encroachment on the medical discipline.
3. Ease of understanding, even by non-medical personnel.
4. Ease of administration.
5. Tests that are capable of being replicated, preferably from written descriptions.

This investigation will attempt to show the feasibility of using

Predetermined Motion Time Systems to accomplish the above objectives within the confines of the criteria stated.

CHAPTER II

CEREBROVASCULAR DISEASE

The type of brain damaged subjects chosen for this investigation fits into a complex category from various causes expressed by the phrase, Cerebrovascular Disease. Stedman's Medical Dictionary[5] defines this in a brief, enigmatic fashion: "Symptoms of brain injury due to vascular insufficiency."

This investigation is not directed toward the nature and causes of the disease, but to means of assessing various effects of the disease. However, it is pertinent to include a description of some of the more common phenomena which could possibly have some effect on motor performance.

Usually accompanying cerebrovascular disease there is hemiplegia, paralysis of one side of the body; or hemiparesis, a slight paralysis affecting one side only. Hemianesthesia, loss of tactile sensibility, may be present. Speech disturbances and vision anomalies can also be manifestations of cerebrovascular disease. Incoordination may be present, and is most readily observed near the end of a motor act.

CHAPTER III

PREDETERMINED MOTION TIME SYSTEMS

History of Predetermined Motion Time Systems

Predetermined Motion Time Systems (PDTS) are considered to be one of two techniques for measuring human work by means of synthesis[6]. The most recent attempt to prepare an Industrial Engineering Terminology Manual[7] produces the following definition of PDTS:

> Predetermined Motion Time Systems (PDT, PDS, PMTS, PDTS) - Systems of elemental manual (sic) motion times covering the principal body and body extremity activities. Predetermined time values have been determined from experimentation and measurement for each significantly different variation of each motion. Segur's Motion Time Analysis (MTA) . . . was the first. . . . The most common . . . are Basic Motion Time Stusy (BMT), Dimensional Motion Times (DMT), Methods-Time Measurement (MTM) . . ., and Work Factor (WF, W-F, or WoFac).

Another definition given by Karger and Bayha[8] follows:

> A predetermined time system is an organized body of information, procedures, and techniques employed in the study and evaluation of work elements performed by human power in terms of the method or motions used, their general and specific nature, the conditions under which they occur, and the application of prestandardized or predetermined times which their performance requires.

Karger and Bayha further describe the aims and ideals of PDTS:

> (Condensed)
>
> 1. The approach and usage of a system must be professional in the best sense of that term.
>
> 2. The system must be based on sound concepts with heavy reliance on the fields of physiology and psychology. Competent personnel should follow . . . scientific (sic) and mathematical rules while developing the data which comprises the working portion of the system.

> 3. The desirability of validating the data . . . is self-evident. . . . Publicity increases the chance for further validation . . . being essential to public trust and confidence in the system.
>
> 4. . . . training control (which) will insure that misuse . . . will not engender a repetition of the "efficiency expert" (unethical) era.
>
> 5. The working form . . . must be practical and practicable to make it adaptable to the solution of many types of work-study problems.
>
> 6. A good system is easy to use.
>
> 7. . . . should be maintained in a dynamic condition to meet the challenge of change.
>
> 8. . . . must give correct answers for actual work situations. . . . reliance must be placed on industrial samples of sufficient scope, range, and size. . . . (As well as laboratory findings) . . . to permit valid conclusions.
>
> 9. . . . universality. Acceptance must be broad, not confined to limits of special industries, or geographical boundaries.

There are no published results of validation of the principal PDTS to allow a conclusion to be drawn that any one system is superior or inferior to another. Salesmanship of the systems is inevitable, if for no other reason than the necessity for technicians to be schooled in the prescribed usage of the systems. Most enterprises do not have the time, qualifications, and more important, the desire to evaluate one system over another. Again referring to Karger:

> The authors' knowledge concerning some of them (PDTS other than MTM) is limited due to lack of published material. . . . valid data can be developed using other predetermined time systems other than Methods-Time Measurement. . . . it is admitted that it (MTM) probably does not excel in every aspect.

Frederick W. Taylor considered the subject of predetermined times as being the eventual result of stopwatch time-study information.[9] It is not likely that Dr. Taylor conceived of a universal set of time data suitable for application to all industries. This may be conjecture based on the activities of the disciples of Taylor, notably Barth,[10] who amassed reams of data of shop operations and proceeded to apply the time data to many enterprises with little or no validation. Their rationale was that "it worked at Midvale, therefore it is good, therefore it is good for this situation."

The pioneers in work measurement lacked definition of the nature of their results. Their use of timing devices alone did not reflect the variations in actual times recorded, due to the inevitable variations in human capacity and motivation, at least. The users were aware of the existence of this defect and realized that a solution would be necessary for a reasonably satisfactory application of time data. It is reasonable to assume that Taylor and his immediate followers were guilty of discarding data that offended their judgment, or made their observations on workers who would produce satisfactory results. (Further assumptions would have to be made to define their conception of "satisfactory" results).

Somewhat later, Frank B. Gilbreth[11] made extensive use of cinematic analyses of minute portions of manual tasks. Their results defined basic elements of work by sixteen "therbligs." The methodology based its analysis on the <u>purpose</u> for which a movement or part of a movement was performed, not on the nature of the movement itself.

For example, if the empty hand moves toward an object, its purpose is to reach that object. Having reached it, the purpose changes first to picking it up, and second, to moving it from one place to another. Three different therbligs are needed to distinguish among these distinct actions:

"transport empty," "grasp," and "transport loaded."

Of the original sixteen therbligs designed and used by Gilbreth, thirteen were active elements and three accounted for the absence of activity. Latter-day practitioners have added two more therbligs for more clarity of purpose.

Gilbreth's original camera work was done with a hand-cranked camera and he later added a chronometer to be photographed simultaneously with the motions being performed. This allowed new opportunities in film analysis because it provided examination of the time relationship of various therbligs. Although users of Gilbreth's techniques felt that a system of quantifying the time for therbligs was feasible, he continued to emphasize that the time required to perform any task was quite unimportant as compared with making the correct sequence of cycle sub-divisions, the problem of least waste of energy involved, and the quality of the resulting product[12].

The therblig classifications emphasized primarily a better understanding of the composition of industrial operations from the workers' standpoint. They were not developed with a great concern for absolute performance time for the therblig elements, but rather to provide an analysis tool for the improvement of manual methods. They did, however, lead to a classification of "elements" adequate for the foundation of what is known today as Predetermined Time Systems.

Specific PDTS

Motion Time Analysis (MTA)

The presentation of Motion Time Analysis (MTA) by A. B. Segur in 1927 is generally accredited as being the first to state a hypothesis concerning PDTS.[13] "Within practical limits, the time required for all experts to perform true fundamental motions in a constant."

Segur describes[14] the derivation of MTA as a result of analyzing films taken of expert industrial operators during World War I. The films were originally made with the objective of being used in the rehabilitation of veterans. According to Segur, the workers studied were the best available in their industry. Analysis of the same motions performed by various workers in exactly the same manner led Segur into making the statement concerning the constancy of elemental times.

Although worker-to-worker variation was noted, Segur felt that this variation was covered by "practical limits." In Segur's words, "As a result of 28* years of experience, it can be stated positively that the greatest average variation in the speed of normal (sic) individuals will be from 10 per cent below normal speed to 10 per cent above normal speed."[15]

Segur further stated that each action of the body is the result of some chemical action that takes place within the body, and since the reaction takes place in a constant (body) temperature, the time for the reaction will also be constant. This constancy becomes the basis for establishing predetermined times (MTA) which are composed of 0.000045 minute per foot of distance traveled for nerve reaction, the average number of messages that can be started over any one nerve path is 5,000

---

*It is not clear whether this is from the start of analysis (1924) or from the date of announcement (1927). This statement could have been made between 1952-55.

per minute, and the average time for a single sarcostyle to complete a contraction in response to a nerve impulse is 0.00064 minute.

Work Factor (WF)

A group of engineers of Radio Corporation of America (Quick, Shea, and Koehler) accumulated data over a twelve-year period, (1934-45) applying the data and modifying it as actual practice demanded. Their efforts were published in 1948[16] under the label of Work Factor (WF or WoFac).

The WF originators describe their method of collecting data as being composed of stopwatch time studies using a rapid watch, photoelectric timers, 16-mm motion picture analysis, and verification of much of the shop data performed with stroboscopic photography in the laboratory. Engineers involved leveled the performance of each portion of data, using two engineers in teams. All data had to be verified or the study was repeated until a consensus time was found.[17]

According to the originators,[18] the final WF times are intended to represent the times required by "an average of experienced workers" as statistically established by large groups of engineers. Since 1945 has been no apparent need for basic revisions in the motion times for WF.

Methods Time Measurement (MTM)

This technique of PDTS had its inception shortly after 1940, and was the outgrowth of an attempt to develop a methods formula for a specific line of work. Analysis of specific operations revealed that data compiled for a specific task (drill press) applied equally well and with a very satisfactory degree of accuracy* to all classes of work involving manual motions.[19]

Cinematic analysis was used to reduce the resulting Methods-Time-Measurement (MTM) time values. For the gross movements, the developers established some intuitive guide lines, particularly in the degree of control required during a movement, or succeeding action. The films were taken at a speed of 16 frames per second, making fine time distinctions very difficult.

MTM test films of walking were made on subjects with a large range of ages (17-65) and a large range of heights (5'-0" to 6'-4"). There is no indication of the distribution of the two sexes, only a notation of heel height was recorded.

Basic Motion Time-Study (BMT)

This plan of PDTS was developed by Ralph Presgrave and Gerry Bailey, staff members of The J. D. Woods & Gordon Co., Toronto, Canada, in 1950.[20] Available literature furnishes sketchy details as to their means of collecting and analyzing data. Apparently the data source is a combination of filming, stopwatch time-study, and verifications at the work place.

Some five years after BMT's appearance, the data was frankly acknowledged to be a revision of MTM data, adding features of some of the other PDTS.[21] The aim of the developers was to achieve easier application and closer differentation of times than they felt was possible with MTM. Many work study personnel have expressed the opinion

---

*It is not clear what "accuracy" connotes in this connection.

that BMT is basically an individualistic interpretation of MTM and is therefore not a distinct PDTS.

Other PDTS

Appendix A shows the chronology and other data of the principal as well as some of the minor PDTS.

Evaluation of PDTS

Many investigators have taken exception to the industrial usage of PDTS, for a variety of reasons. Notable among these are Abruzzi,[22] Buffa,[23] Davidson,[24] Ghiselli and Brown,[25] Gomberg,[26] and Nadler.[27]

In summary, their principal exceptions or descriptions of possible errors are:

1. The effect of interdependence or nonadditivity of motion times.

2. Discreteness of motion categories and time values assigned, rather than some continuous function.

3. Errors contributed by the practitioner himself.

4. Assumption of a flawless performance.

5. Sampling errors in original data used for development of the various PDTS.

6. Failure of most PDTS to recognize the same variables.

7. Effects of practice or extended learning.

Industrial claims of "accuracy" superiority attributable to PDTS can be refuted by taking an objective view, such as expressed by Reuther;[28] " . . . (PDTS are) subject to all the major defects of standard time study technique plus a few others besides." In December, 1961, the Fourth Constitutional Convention of AFL-CIO unanimously adopted a resolution, which included;[29] " . . . after many years of trial, (labor) is forced to conclude that these (PDTS) techniques are based on the same or similar assumptions . . . of the Management Engineer."

Krick[30] concludes that the authors who attempt to detract or condemn PDTS on the basis of the systems' own errors fail to recognize the practical problem facing management which must have time estimates to operate satisfactorily. All techniques of time estimating have inherent errors. The feature of PDTS which makes them techniques for comparison purposes is the ability to synthesize tasks in such a manner that the small elements of motion may be compared out of context rather than making comparisons of the entire task.

CHAPTER IV

PSYCHOLOGICAL TESTING OF BRAIN DAMAGE

General Discussion

Psychologists have been evaluating brain damaged patients for many years, employing tests of intelligence, perceptual-organization (loss of integrative perception), motor performance, and others.

The principle underlying psychological testing is that old, well-established habits and modes of behavior (such as word knowledge) show relatively little loss, whereas, new learning, newly acquired associations, performing new tasks, and solving new types of problems are impaired in cases of organic brain damage.[31]

The interpretation and standardization of the tests is complicated by the fact that allowance should be made for normally expected loss at advanced ages; and individual differences in cultural, educational, and occupational backgrounds must be considered in evaluating a subject's performance. If there is psychiatric disturbance present, the validation of this problem is in itself sufficiently inconsistent and lacking in reliability as to introduce an important source of error.

One of the primary difficulties involved in psychological testing of stroke victims is a base of comparison prior to the stroke. Since prediction of an occurrence is very unlikely and the age range is quite large, there is little likelihood of the existence of pre-stroke information concerning each subject's psychological reference base. Further, what should be tested seems to elusive, since each subject's progress during recovery is highly individualized when considered on a short term or day-to-day comparison.

More Common Psychological Tests Applied

Intelligence

The Wechsler Adult Intelligence Scale (WAIS) is a revision of the Wechsler-Bellevue Intelligence Scale. The range of difficulty is extended in order to assure a score for the lower level of mentally deficient subjects. The vocabulary subtest is devised to produce a fairly normal distribution of scores for a representative sample of the population. Maximum scores in verbal and nonverbal tests and in the full scale are reached by the 25-34 age group.

Appendix B illustrates the functions tested in the various subtests.

Perceptual-Organizational

This type of testing is epitomized by the Bender Visual-Motor Gestalt[32] test, devised by Max Wertheimer--one of the founders of the Gestalt school of psychology--in his experimental work on perception. The underlying principle utilized in this Bender test is that organized wholes (structured units) are the primary forms of perception in human beings. Disturbances of perception (loss of integrative perception), therefore, might be psychopathological manifestations. Perceptual behavior is regarded in the test as involving sensory reception of the figures, interpretation at the central levels of the nervous system, and motor performance (drawings). This total process of perception and reproduction can be distorted by neural injury (stroke), by emotional maladjustment in the perceiving individual, and by variations in the level of intellectual performance.

The Bender test explores the possibilities of evaluation of perception by investigating the "gestalt functions" in cases of aphasia, organic brain disease, and many categories of psychiatric disturbances. For purposes of brain damage and its effect on manual performance, the Bender test is evaluated for: motor incoordination; poor motor control representing physiological tensions or poor muscle tonicity; movements used in making drawings, e.g., speed, rhythm, perservation; form of the drawing, e.g., outline, arrangement, spatial orientation, form differentation, size and omissions.

In addition to the evaluation of the subject's drawings, the examiner also observes the behavior of the subject during the testing process, noting the methods used, verbalizations, and attitudes.

Motor Performance

Many types of tests are used in the determination of psychomotor performance, or the demands on mind-muscle cooperation. The majority of these tests are for vocational selection or pre-employment screening and concern themselves with evaluating speed, simple reactions, coordination, as well as perceptual factors. Others test speed of gross movements of hand and arm, manual rhythm and coordination, and finger control and coordination.

Gross movements of hand and arm employ tests which measure in terms of speed (total time) with which the subject picks up small pegs and places them in a hole, or larger cylindrical objects in an appropriate hole. Typical examples of these are: Purdue Pegboard,[33] and Minnesota Rate of Manipulation Test.[34]

It should be emphasized that these tests are timed, reproducible systems of testing which isolate the motor performance from the non-motor factors to a reasonable degree, but the time data is collected in the total; that is, for all types of movements involved in performing the entire group of cycles. Also, these tests are not designed specifically for the handicapped or other dysfunction, in fact the tests proclaim their advantage to be that "anyone" can perform them.

CHAPTER V

EXPERIMENTAL PROCEDURE

General Description

The experiments performed consisted of making observations of one principal unilateral manual* task with a modification permitting the conversion of this task to a bimanual task; a secondary task designed to evaluate acceleration, velocity, and deceleration of the upper extremity. Each test was designed for a different set of objectives and therefore shall be described separately. All subjects were selected** brain damaged subjects and the affected upper extremity was the object of interest.

Description of Tasks

Task 1

The first task was essentially similar to a task described by Hancock and Foulke.[35] The motion sequence involved the MTM elements, Reach, Grasp, Move, Position, and Release. Analysis of many sample industrial tasks of a manual variety show that these elements or motions comprise 97.5% of all motions used.[36]

---

*Throughout the remainder of this writing, the loose definition of "manual" will be used. This denotes movements of the involved portions of the upper extremity, but precludes extreme bending or twisting of the trunk.

**See p. 29 for manner of selection.

Specifically, the task consisted of: 1) obtaining a metallic or wooden peg, three inches in length and 0.404 inches in diameter, lying jumbled in the mouth of a gravity feed bin, the mouth being five inches in width by four inches in height; 2) transporting the peg to a vertically oriented target hole, 0.4564 inches in diameter; 3) placing the peg in the target hole and allowing it to fall by gravity to a receptacle; 4) reaching to a lever; 5) depressing the lever; 6) releasing the lever; and finally, 7) reaching to the bin holding the pegs to repeat the sequence exactly.

The layout of the task area utilized a conventional card table, with a modified surface to accommodate the bin, lever, and target hole. In each use, the table surface was oriented horizontally with reference to the earth's plane, as well as horizontally oriented with respect to the floor, ceiling, walls, windows, seat, and other surroundings. Figure 1 shows the original dimensions of the task area with all pertinent devices resting or fixed to the table's surface. After a very few tests the layout was modified to the configuration shown in Figure 2. This was done to obviate frequent reorientations of appertenances occasioned by the necessity to observe the paretic extremity, whether left or right, or later when bimanual tasks were observed. This modification still conformed in its essential similarity to the task as described by Hancock and Foulke. This was later verified.[37]

The subject was seated in a comfortable position before the table where the work task had been previously arranged. Verbal instructions were given in a conversational, informal tone, instructing the subject to perform the task as previously described. During the verbal

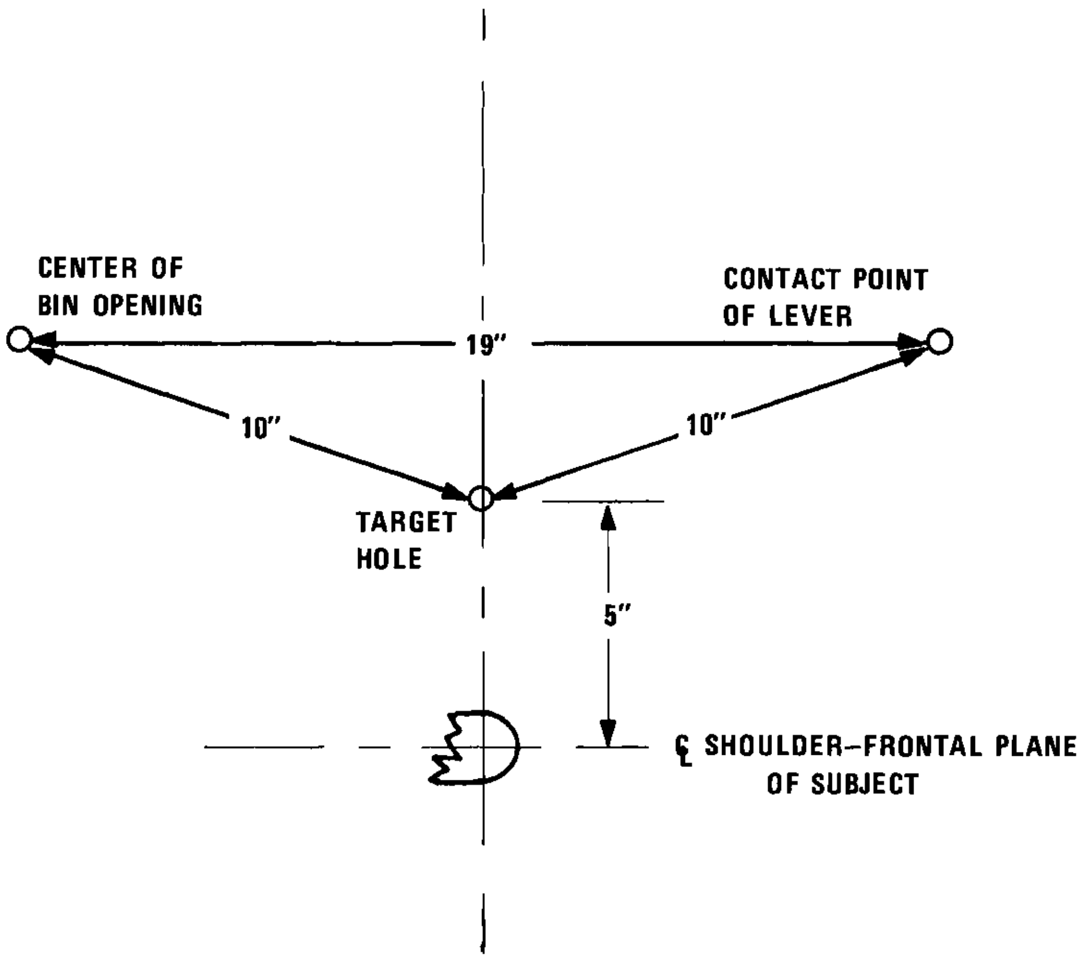

Figure 1. Dimensions and Layout of Task 1 as Employed in Test of Right Upper Extremity. Positions of Lever and Bin are Reversed for Testing the Left Extrenity. (Before Modification).

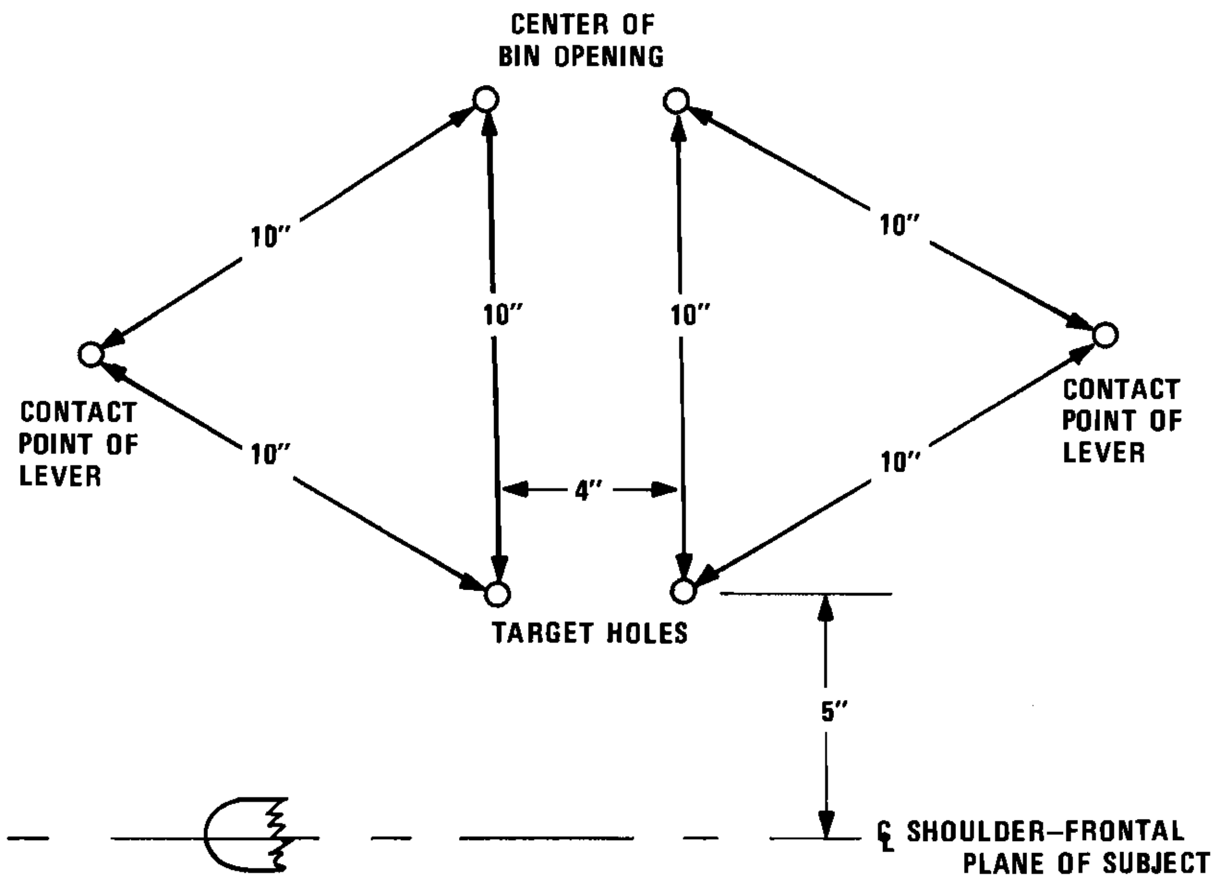

Figure 2. Dimensions and Layout of Tast No. 2 as Employed with Either Extremity, or Bimanually and Simultaneously. (After Modification).

instructions, the observer either touched or nearly touched each of the points, such as the target hole, the lever, etc., and in a figurative fashion, traced the motion path and the sequence of motions to be followed. Admonitions were given requesting that the subject attempt to perform the task as fast and as accurately as possible. The paretic limb was the area of test interest.

All subjects were then filmed without allowing any preliminary manipulation, or assessment of the task. Approximately two minutes of action was filmed.

After the first trial was completed, the subject was permitted to relax while the equipment was resupplied, or film loaded. A second trial was then performed, again using the affected member for test. The same elapsed time was filmed. A third sequence duplicated the first and second sequences, again with the affected member as the interest.

Task 2

The second task employed the same facilities and motion sequence as for Task 1. The difference was the sequence of extremities tested. The verbal instructions were given to do the task with only the paretic member. After filming and a relaxation interval as in Task 1, the subject was verbally instructed to repeat the task as previously performed, but using both hands simultaneously, symmetrically, and oppositely. Admonitions were given to not let the affected limb fall behind the unaffected limb, and conversely, not to let the unaffected limb work ahead of the affected limb. As in Task 1, speed and accuracy were stressed.

After two minutes of filming, a third sequence was performed, documenting the actions of the paretic limb alone. The second filming was not analyzed.

Task 3

This task employed stroking[38] on the horizontal surface of the table, horizontal denoting the same conditions as for the other tasks. The work table held a semicircle inscribed and radii of 10 inches in increments of 30°. (Figure 3).

The purpose of this was an attempt to measure the degree of change of motor character activity of the upper, paretic extremity, from the standpoint of radial direction from the trunk. Secondarily, there were reasons to expect that a brain damaged subject would not demonstrate the same pattern of manual acceleration, velocity, and deceleration as a non-affected person.

The subject was given verbal instructions to stroke, using his paretic limb, with his finger from the center of the semicircle to the first point parallel to his shoulder frontal plane, back to the center point, then to the point on the semicircle described by the arc subtended by the 30° increment, back to the center, to the next circumferential point at the 60° increment, etc., repeating the sequence until filming was complete. No planned dialog or instructions were used, rather the subject was led to understand in his own fashion. The subject was allowed to practice, was corrected as required, and when the subject felt that he was performing as well as he could, the filming actually began. Any rest breaks desired were taken, for the effects of fatigue were hoped to be avoided.

Task 3 was disbanded for reasons which will be described in the analysis of tests.

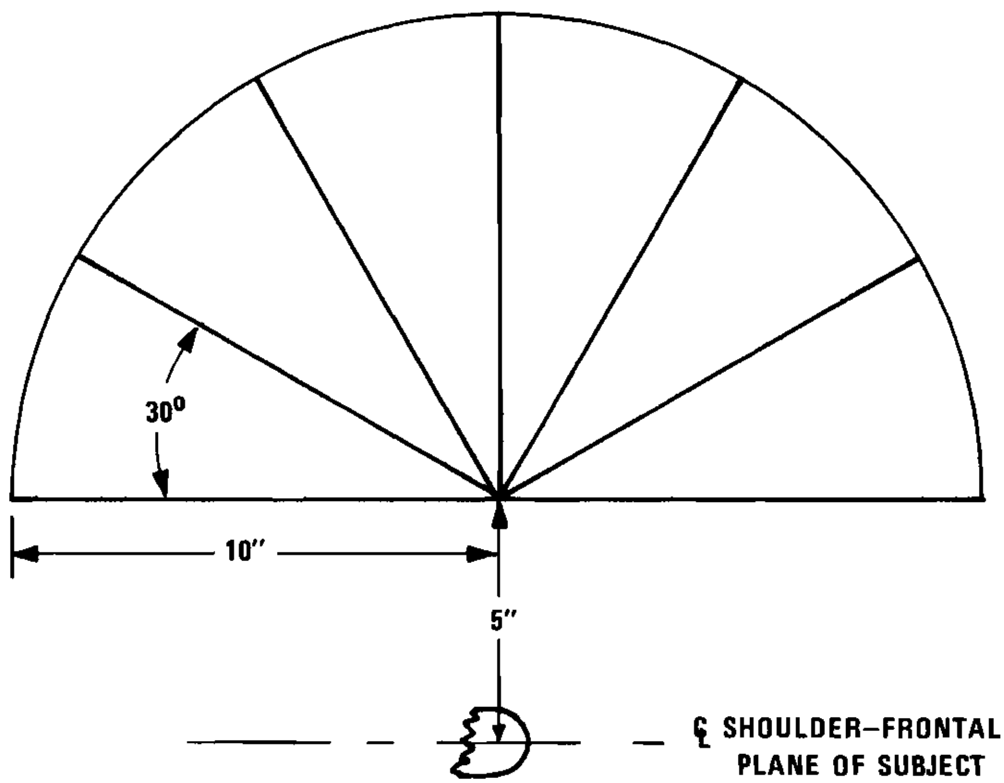

Figure 3. Dimensions and Layout of Task No. 3 as Performed with the Right Extremity. Left Shoulder Would be Placed at Location for Test of Left Extremity.

CHAPTER VI

EXPERIMENT FACILITIES

Work Place

The work place was designed to conform as nearly as possible to a task described by Hancock and Foulke.[39] A chair placed at the work table allowed free movement of the upper extremity with the elbow fixed at the side. Verbal instructions, admonitions, and eventually a mild restraint as a reminder was used to preclude the subject's being able to perform the task primarily with the use of the trunk. This was done in order that the observations could be made of the upper extremity's movement. Although it is recognized that shoulder girdle and trunk muscles are involved in movements of the arm, the restriction of torso movement did not eliminate the subject's ability to use whatever muscles required to perform the tasks, but did ensure that the upper extremity performed the task in a dynamic fashion rather than as a passive holding device controlled by torso manipulation. Although the practice of MTM would allow analysis and synthesis to be performed with any combination of members used,[40] it was desirable to make the tests as uniform as possible.

The subject was freed of as much distraction as possible, limiting the appertenances of the table to the required equipment; and other personnel barred except for the principal observer, a physician or advanced medical student, and a camera operator. The majority of the observations were made utilizing ambient light.

The chair employed varied at times, but with the exception of patients in wheelchairs, the chair employed was within tolerances recommended by many investigators[41] for clinically normal persons of the 50th percentile.

Gravity feed bins were of the type with a completely open top. This would have allowed more area for the subject to choose (Search and Select) the peg to be grasped. Further, it would have created a variable location of the pegs. Consequently, the top was masked off to conform to the dimensions stated in "Experimental Procedure."

In view of the purposes of the presence of the lever, several minor modifications were made in construction details. One of the purposes being to create a Case "A" Reach, the dimensions of the lever "face" were generous, 3" x 4". This assured that the lever could be touched and depressed with a great amount of latitude insofar as accuracy of contact was concerned. A mild spring resistance was included, but if a particular hemiparetic subject could not depress it to the stop, he was instructed that moving the lever downward would be sufficient.

Timing Device

For timing as well as a record for analysis, a Bolex HK-16, Reflex 16 mm movie camera was employed. The camera drive uses a synchronous electric motor, and except where noted, all sequences were photographed at 16 frames per second or 960 frames per minute.

(At 16 frames per second, there are 60 x 16, or 960 frames per minute. This would give an elapsed time between frames exposed of 1/960 minute. For convenience and in recognition of the nature of the experiments, it was chosen to consider each frame as representing 1/1000 minute.)

The camera shutter was variable from 180° to 0° angle of exposure. In order to utilize ambient lighting as much as possible, the shutter angle was 180° for all sequences. The maximum film capacity of the camera was 100 feet, or about 4 minutes of filming, which placed some limitations on the scope of the tests.

Experimental Subjects

The subjects tested were from the inpatient or outpatient service of Grady Memorial Hospital and Emory University Hospital. All had suffered brain damage of the cerebrovascular disease type, with the exception of one subject who suffered the same effects as a result of a traumatic accident. The medical staff of the hospitals selected the subjects as being satisfactory for test purposes.

The patient population was composed of hemiparetics whose residual motor function of the involved upper extremity included:

1. Ability to grasp, be it three-finger pinch or having an all-finger grasp.
2. Ability to release grasped object;

in both instances grasp and release was considered satisfactory even if clinically it appeared awkward; hemiparetics were excluded from this study if they had either central nervous abnormalities or visual abnormalities or astereognosis (inability to recognize objects by light touch only); or if their motor impairment was of the cerebellar type; of if they had involuntary movement; or if they had central nervous system type impairment of understanding verbal or typed commands.

All screening tests performed by the medical staff were retained for proprietary reasons, as well as the subjects' clinical history. A sample clinical history is shown in Appendix C, and a sample of the screening test in Appendix D.

CHAPTER VII

ANALYSIS OF TESTS

Selection of PDTS

The Predetermined Motion Time System selected for making assessments of brain damaged subjects was Methods-Time Measurement (MTM). The principal reason prompting this decision was the availability of published reports of results of MTM-sponsored research performed by the Department of Industrial Engineering, University of Michigan. Although these reports are MTM-sponsored, the research performed is directed by the faculty, and believed to be of scientific nature rather than a continued support of user credulity. The present director[42] asserts that no research is being directed toward validation of published MTM time values, for the same reason previously stated, i.e., that all work measurement techniques have inherent errors.

On the other hand, the MTM Research Reports are a ready source of experimentation performed which relates MTM elements and their characteristics to such areas as learning, correlation of experimental studies with industrial experiences, correlations of MTM time values with physiological functions, etc. By duplicating the test layouts of the MTM research and relating their results as performed on physically normal subjects, one very tedious step of research is obviated.

The selection of MTM as a basis of comparison does not construe an endorsement of validity of its elements and time values, nor does it reject the possibility of some other PDTS being employed for the same purpose. The sincere detractors of PDTS usage seem to converge about one axis--the flawlessness implied. This investigation need not concern itself with the flaws or lack of validation. For example, the interdependence or nonadditivity of the time values was not considered during the testing and analysis, since the objectives were actually opposed to the total performance of a brain damaged subject. Absurdly stated, any arbitrary or experimental time value could have been generated for use as a basis of comparison of each microscopic motion performed by the subjects. Isolation of motor character activity of the subunits of the upper extremity, documentation of degree of change or improvement in motor performances, etc., is relative to each subject rather than relative to the physiologically normal industrial worker. Selection of any other base--arbitrary or developed--would have constituted useless innovation merely for the sake of innovation, possibly causing criticism being directed toward the base rather than the use of the base in documenting relative performance.

Analysis of Data

In view of the wide range of actual times observed in the same hemiparetic subject performing the same element, a medical assessment of such results would require a more critical view of the range of times obtained. In the evaluation of the course of hemiparesis the physician could possibly have the physiologically possible time as an objective statement, rather than large amounts of statistically qualified data that includes fumbles, flaws, distractions, motivational variables, etc.

No attempts have been made to select representative data, or to discard data which appeared either extremely high or low. Joint efforts with the medical profession towards some selection to fulfill a particular medical objective could only justify any selective process of the data obtained.

The developed films were analyzed frame-by-frame to derive the actual time for each MTM element performed. A conventional frame-counting cinema projector was used. The motions involved with depressing and releasing the lever were not analyzed. Excluding these motions was in keeping with employing a pertinent motion sequence approximating the task as originally described by Hancock and Foulke. Although the test procedure employed with the brain damaged subjects employed a lever, Hancock and Foulke utilized a knob to be rotated about 6°.[43] The purpose of including the knob was to generate two distinct types of Reach, and to add to the entire cycle time with some different, intervening motion.[44]

The actual times found by cinematic analysis for each of the subjects and each of the MTM elements was reduced to punch card data and statistically analyzed in part employing the RECC UNIVAC 1108 computer. A library program of simple linear regression plus a digital print out of actual MTM elemental times and the regression line was the output. Additionally, significance tests were made of selected samples using a PDP-8/S digital computer (Digital Equipment Corp.) located in the School of Industrial Engineering.

At this level of investigation, a statistical description of brain damaged persons as a population sub-group is not feasible or even desirable. Therefore, each subject was essentially tested to indicate individual upper extremity sub-unit motor character activity.

The mean actual time for performing each MTM element by each subject's paretic extremity was compared as a ratio to the "normal" time as published by MTM. It should re re-emphasized that the comparisons made of a brain damaged person's performance index with that of "work measurement" MTM time did not consider that the objectives included means of improving the hemiparetic's recovery to the performance time of a clinically normal person. Rather, the obvious consistency of a benchmark time would rule out subjectivity when stating the condition and monitoring the change of the course of hemiparesis.

It is this numerical comparison, performance index, of the actual time consumed by the individual subjects to the established MTM time for the same motion that is considered to be definitive measure of: motor character activity, change of such character, isolation of subunits by comparison, the beneficence of therapy, etc.

Other tests of the data obtained were used, but inconclusive results precluded further examination, possibly until simpler means of collecting, recording, analyzing, and reduction of data can be employed. For example, "tests of runs" to be confident that the time data collected was a random variable showed illogical results from the same subject during the same work cycle, but on different MTM elements. In part, this will be discussed more fully with the results, conclusions, and suggestions for further investigation.

Discussion of Results

Task No. 1

P1SE + RL1. Table 1 shows the tabulation of results for the combined MTM elements P1SE + RL1. The MTM element of Position (P) is described briefly as: " . . . the basic finger or hand element employed to align, orient, and engage one object with another to attain a specific relationship."[45] Further restraints or conditions explained in the MTM Application Data[46] identify " . . . class of fit-1-loose; no pressure required;" . . . symmetry, S--symmetrical--the parts can be engaged in an infinite number of ways about the axis of insertion:" " . . . Easy to handle-E- . . . must be based on considerations of the rigidity of the part, its size relative to its weight, and the manner of grip the worker has on it."[47] Therefore it was judged that this motion tested fitted the established description of P1SE, symbolizing the symmetrical positioning of an easy-to-handle part into a loose fit with the engaged part. This also corresponded with MTM Research Report #112 as mentioned earlier.

As noted above, the Release, RL1, was combined with the MTM element P1SE. Release is possibly the simplest motion performed by a normal person. Defined as, " . . . basic finger or hand motion employed to relinquish control of an object,"[48] the eyes can hardly detect the motion-only the effect of relinquishing control of an object. Logic would indicate that it must take place, therefore analogy has been employed to determine the MTM time for this element. MTM practice considers RL1 as " . . . opening the fingers as if in a separate, distinct motion."[49] The object may be dropped, freed from restraining action,

Table 1. Tabulation of Results of Combined MTM Elements P1SE and RL1. (MTM Time = 4.56×10^{-3} Minutes)

Sample Number	Data Points	Arithmetic Mean Time (Min. x 10^{-3})	Standard Deviation of Sample Mean	Slope of Regression	Performance Index
304	7	36.57	14.89	0.82	0.12
322	14	25.64	8.44	0.43	0.18
216	9	72.00	48.57	-11.08	0.06
222	20	89.70	47.29	3.54	0.05
504	66	11.52	3.62	-0.04	0.40
504A	33	13.83	4.91	0.04	0.33
410	27	20.52	8.17	0.03	0.22
434	33	18.06	5.05	-0.07	0.25
328	29	17.31	7.46	0.11	0.26
334	31	16.74	5.03	0.09	0.27

or merely left to rest on a supporting surface.

Due to the nature of the movement and the MTM assigned time for RL1 (0.0012 minute),[50] it is virtually impossible to determine the exact instant of beginning and end of RL1 using a motion picture camera, for as employed, the shortest time unit was 0.001 minute. Also the inherent design of present cinema equipment practically precludes RL1 being "seen" by the camera in every instance. For these reasons, Position and Release were combined in the analysis.

It is conceivable that a brain damaged person would consume more time than a normal subject while performing Release. Logic would indicate that this additional time might be consumed in "willed motion." If this were true, the Release would be delayed by some deficit not measurable with a camera.

The hemiparetic person generally could not hold the peg or dowel in a conventional fashion, which will be discussed under the heading of Grasp. This awkward holding frequently resulted in rather long elapsed times for P + RL, and considerable variation in the individual times obtained for each case.

It should be noted that many medical studies documenting recovery from hemiparesis of the upper extremity[51] demonstrate that in the majority of instances digital segmental motion recovery was the first subunit in manifesting signs of recovery. This does not necessarily indicate usage of the distal portion as conventional motion analysts might visualize, i.e., conventional digital coordinate usage with vestiges of control.

<u>M10C</u>. Table 2 tabulates the results of the MTM motion element,

Table 2. Tabulation of Results of MTM Element M10C
(MTM Time = 8.10×10^{-3} Minutes)

Sample Number	Data Points	Arithmetic Mean Time (Min. $\times 10^{-3}$)	Standard Deviation of Sample Mean	Slope of Regression	Performance Index
303	8	19.63	6.70	0.32	0.41
321	14	12.00	2.18	0.07	0.68
215	9	13.56	4.90	-0.28	0.60
221	19	17.63	7.90	0.55	0.46
503	67	10.00	2.00	0.93	0.80
503A	33	11.24	2.24	0.05	0.72
409	27	10.59	3.48	-0.02	0.76
433	33	6.88	1.73	0.03	1.18
327	29	7.76	1.96	-0.04	1.04
333	31	6.71	1.30	-0.04	1.21

Move. Move is described[52] as . . . "the basic . . . motion employed when the predominant purpose is to transport an object to a destination." The types of Move are further classified by MTM, with a Case "C" move being " . . . (moving) an object to an exact location." Typically, a Case "C" Move implies that the hand will transport the object to within one-half inch of the destination point. This would require sufficient control of the object being held to cause a slower time than a similar Reach. Also, a certain amount of eye-hand coordination would account for additional slower time than a Reach. The subject must be looking at the destination point, or there must be some way in which equivalent information can reach his mental centers via space perception. (MTM training[53] describes this erroneously as "kinesthetic sense.") The MTM description of a Case "C" Move[54] points out that . . . "a Case C Move (is) followed by a position." The more important corrolary of MTM usage states " . . . that Positions are always preceded by Case "C" Moves."

Weight of the object being moved, or resistance encountered in motion should be taken into consideration as affecting the time of performance. Since the object being moved weighed less than 2.5 pounds, and encountered only air resistance, the adjustments suggested by MTM would not apply, since the task requirement was considerably below the weight requiring further adjustment of the MTM base time.

The distance moved is a determinant of the total time for the Move. An industrial worker will generally perform a spatial horizontal move (also a Reach which will be discussed later) in a curvilinear path. The distance considered when employing MTM time values is the arc distance rather than the net, or effective distance. The film analyses showed that brain damaged subjects did not naturally follow a curvilinear path. Some isolated cases indicated that the movement was actually three separate movements with microscopic "halts" at a change of direction. These movements resembled three-sided tracings of rectangles, rhombuses, or trapezoids. This imperfect duplication of a typical Move was considered acceptable because of limitations of timing devices. Therefore, the net travel distance was stated and used in order that replications could be performed without resorting to pretrials to determine the spatial travel distance of the handicapped subjects. Again, this points out that the comparisons made include quality of movement as well as quantity.

The angular direction of Move is considered to be a factor affecting the time for a brain damaged person to perform an act. This is evidenced in a normal person also, but the time differential is considered to be negligible, particularly when very light weight is involved.[55] In many of the cases, the Move, which was performed towards the body demonstrated a higher index of performance than did Reaches away from the body. All other factors being the same, such disparity should not be expected. Discussions with Schwab indicated that his original investigations whosed some lessening of the time when the Reach or Move was made toward the body, however statistical inferences did not substantiate or justify making a distinction for industrial usage.[56]

Gravitational effects, the length of the moment arm, are recognized as possible determinants of the MTM time for Move and Reach, but the absolute quantity does not seem to be significantly large to be of concern in industrial usage of MTM. It would seem logical that a brain damaged person would encounter a greater proportion of effect on movement time due to gravity on the extremity alone due to his paretic condition. Again, the limitations of the camera as a timing device ruled out any attempts of quantifying gravitational effects.

Another factor which would affect the Move time for a brain damaged subject would be the MTM motion described as Regrasp, or Grasp, Case 2. This is the shifting or realigning of the object to be positioned in order to improve control or location of the object in the hand for later use. Visual analysis of the films made showed very few attempts to do this action while the Move element was being performed. Intuitively, it appeared that the brain damaged subjects had gained as much control as they considered possible while performing the original Grasp. Any attempts to improve the orientation of the peg for later positioning seemed to be a shifting or twisting of the entire trunk. As mentioned earlier, a mild restraining device was introduced to obviate the subjects' unconscious use of any body member other than the upper extremity. This was not wholly prohibitive, but the nature of the use of the results seem to make this infrequent assistance numerically unimportant.

Over and undershooting of the target hole was also observed while collecting time data. This can be attributed to two reasons, probably occurring simultaneously: 1) The task was timed from the first trial following verbal instructions; 2) The nature or typical manifestations of hemiparesis, i.e., incoordination. Since the objective at this point was a comparison, the time consumed in performing the Move included the time for extraneous movement, realizing that later, further testing on the same subject will show whether any improvement has resulted. This improvement would be a composite of quantity as well as quality of movement.

G4A. The next MTM element analyzed, shown in Table 3, is G4A. This element is defined as[57] ". . . the basic finger or hand element employed to secure control of an object." A type "4" Grasp is described as ". . . to obtain control of a single object from a jumbled pile of objects when the act of search and select must precede closing of the fingers." Further, the object size justifies the Case "A" by exceeding a size of 1" x 1" x 1."

To understand the nature of Grasp, the one outstanding fundamental objective is "control." As discussed in the analysis of the MTM element Position, the empirical assumptions of finger-thumb-palm involvements were not employed by some hemiparetic subjects.

Grasp and Position, although almost subconscious actions to a trained normal subject, appear to be the most difficult tasks for the hemiparetic subject. Poock[58] postulates that the MTM time for performing a Grasp or Position is:

Time = Constant + b (visual acuity) + c (tactile) + d (finger dexterity) + e (eye-hand coordination) + f (decision making) + g (recoding) + ε (error)

His conclusions concerning a one-handed Grasp[59] indicated that performance time depended highly upon the decision making ability and finger dexterity of an individual. His investigations were all performed on subjects ostensibly without brain damage.

If Poock's conclusions concerning the most important determinants of Grasp and Position performance are to be related to the performance time of a brain damaged person, there is some medical evidence to support this conclusion.[60] For example, the rolandic region of the

Table 3. Tabulation of Results of MTM Element G4A
(MTM Time = 4.38×10^{-3} Minutes)

Sample Number	Data Points	Arithmetic Mean Time (Min. X 10^{-3})	Standard Deviation of Sample Mean	Slope of Regression	Performance Index
302	8	59.63	23.75	0.77	0.07
320	14	32.50	16.48	0.61	0.13
214	9	46.67	20.63	1.55	0.09
220	19	37.00	23.64	0.44	0.12
502	67	8.10	4.00	0.02	0.54
502A	33	7.80	4.65	-0.23	0.56
408	27	14.81	6.51	0.21	0.30
432	33	11.73	4.37	-0.04	0.37
326	29	16.10	4.27	-0.01	0.27
332	31	18.90	1.26	-0.13	0.23

cerebral cortex is a "stereognostic apparatus for exploring space," based on contactual modifications of proprioceptive reactions. The steps in recovery from loss of motor function in hemiplegia begin with the simple and then the more complex. Although the first signs of recovery may appear distally, flexion and extension in the fingers may be slow and clumsy. Twitchell[61] observed that finger and wrist willed movements were enhanced by the addition of the shoulder-elbow flexion synergy. Further, the grasp reflex was never obtained in the absence of some voluntary movement.[62]

Concerning Poock's determinant of decision making ability, it is very difficult for this investigator to find or properly interpret hypotheses or opinions concerning the measurement of decision making ability in a brain damaged subject. It can only be noted that many varieties of abnormal motor manifestations are associated with hemiplegia.

R10A and R10C. Reach, the next MTM element observed, has many of the qualities of Move as discussed earlier. The observations shown in Tables 4 and 5 represent two cases of Reach. Reach is described by MTM[63] as " . . . basic . . . motion employed when the predominant purpose is to move the hand or fingers to a destination." The observations were made of Case A and Case B Reaches.

Case "A" is reaching " . . . for an object in a fixed location. . . ." This implies that the fixed location is exactly the same each and every time. From a practical sense this does not imply that the object be bolted down, but rather the mental certainty of the object's location. This mental certainty is gained after practice by normal workers. Many writers in the field of industrial work measurement

Table 4. Tabulation of results of MTM element R10A (MTM Time = 5.22×10^{-3} Minute)

Sample Number	Data Points	Arithmetic Mean Times (Min. X 10^{-3})	Standard Deviation of Sample Mean	Slope of Regression	Performance Index
300	8	31.88	8.54	2.92	0.16
318	15	24.33	5.94	-0.46	0.21
212	10	22.40	11.22	-0.51	0.23
218	19	22.47	9.58	0.71	0.23
500	67	8.05	2.18	-0.07	0.66
500A	32	8.00	1.85	0.05	0.65
406	27	8.11	2.31	-0.02	0.64
430	33	6.76	1.20	-0.01	0.77
324	30	8.00	1.29	-0.10	0.65
330	32	6.69	0.86	0.02	0.78

Table 5. Tabulation of Results of MTM Element R10C (MTM Time = 7.74 X 10^{-3} Minute)

Sample Number	Data Points	Arithmetic Mean Times (Min. X 10^{-3})	Standard Deviation of Sample Mean	Slope of Regression	Performance Index
301	8	22.13	6.70	0.87	0.35
319	15	14.93	2.99	-0.00	0.52
213	9	19.89	12.18	-0.90	0.39
219	18	15.94	4.94	-0.04	0.49
501	67	7.86	1.07	-0.05	0.99
501A	33	9.45	1.06	0.08	0.82
407	27	6.74	1.16	0.04	1.15
431	33	6.03	0.73	0.03	1.28
325	30	6.90	1.58	-0.10	1.12
331	31	5.68	0.83	-0.02	1.36

loosely, or incorrectly describe this mental certainty as "kinesthetic sense." The more proper usage is "space perception" describing the mental processes involved in perceiving oneself, or oneself's relation in space to an object.

Most industrial workers who can justify their continued employment have sufficient space perception to perform Case "A" Reaches without visual assistance, or at least, a minimum amount of peripheal vision. A specific Case "A" Reach performed many times during short-cycle tasks is probably the most sub-conscious motion made with the possible exception of RL1. Practitioners of MTM synthesis and implementation judge that any Reach terminating anywhere within three inches of the body is classed as Case "A." This is occasioned by the mental certainty of the body's location.

Considering a brain damaged subject, the effect of space perception is not simple, empirical, and taken for granted as in the worker population. As mentioned earlier in the brief description of cerebrovascular disease, many patients suffer with a variety of anomalies which may affect the quality of upper extremity movement. These anomalies are generally a subject of interest for the physician, but this investigation shows the net effect of abnormality, rather than the quantities of each contributor.

The Case "C" Reach differs from Case "A" in that the objective is is[64] " . . . reach to an object in a group of objects which are jumbled so that search and select occur." MTM rationale for the increased time for Case "C" is that greater muscular control is required, in addition to the mind and the eye selecting which object is to be grasped before grasping action can occur.

As in the MTM element Move, a performance time determinant of Reach is distance. The observations made and resulting analyses of the hemiparetic subjects of this investigation considered the net travel distance for Reach for the reasons as described earlier when considering Move. The previous discussion concerning angular direction of the MTM element Move apply to the element Reach also.

All MTM Elements. Table 6 presents the same information contained in Tables 1, 2, 3, 4, and 5, but arranged in order of performance by two subjects. This arrangement of data presentation could serve as:

1. An immediate comparison of the amount of dysfunction of each sub-unit of motion for a specific patient.

2. A comparison of two or more subjects by sub-units.

3. A record or history of change in motor character for many specialties in clinical usage.

4. An eventual possibility of matching degrees of motor character of a handicapped person with the demands of given occupations in industry or business.

Discussion of Results--Task 2

Task number two was designed to determine if there could be a change in motor activity character of the hemiparetic when certain "principles" of motion are employed. Most writers, significantly Barnes[65] and practitioners of methods improvement subscribe to a body of traditional knowledge commonly referred to as "Principles of Motion Economy." These "principles" are predominantly empirical in nature,

Table 6. Results of Task 1 Shown in Order of Performance For Two Subjects; "M" and "J"

Sample Number		MTM	Performance Index	
"M"	"J"	Element	"M"	"J"
212	324	R10A	0.23	0.38
213	325	R10C	0.39	0.65
214	326	G4A	0.09	0.15
215	327	M10C	0.60	1.00
216	328	P1SE+RL1	0.06	0.10

based on common sense, and supported by years of application in practice.

Since the brain damaged person was the object of interest in this investigation, and more specifically, the hemiparetic aspects of the upper extremity, it seemed natural to observe the effects of the motion "principle" referred to as "symmetrical workplace." It states:[66] "When feasible, motions of the left and right hands should be simultaneous and in symmetrically opposite directions."

Symmetrical motions have frequently been misapplied in industrial practice. It is suggested that the abuse arises from the non-experimentalist observing the ease of learning of symmetrical motion patterns on the part of the worker. This facility reduces training time and could lead to an erroneous conclusion as to the real benefits of symmetrically opposite motions. The ease of learning a symmetrically opposite set of motions gave rise to making observations of a brain damaged subject's performance when doing such a task.

Table 7 illustrates the results obtained from observations made on one brain damaged subject performing a symmetrically opposite set of motions (in part). Trial No. I indicates the performance index for each MTM element as performed by the paretic extremity.

Trial No. II is the results of observations made on the same extremity after a period of relaxation and about two minutes of performing the entire task bilaterally, followed by a second brief period of relaxation. For emphasis, Trial No. II was performed with the paretic limb alone.

In each MTM element there was a significant change noted--change toward a higher Performance Index. It should be noted that the greatest

Table 7. Results of Trials I and II, Task 2

Sample Number	Trial Number	MTM Element	Performance Index	Standard Deviation of Sample Mean	Level of Significance (2-tail)	Apparent Degree of Change (%)
700	I	R10A	0.44	3.79	0.01	+43%
712	II		0.63	1.61		
701	I	R10C	0.70	2.45	0.01	+61%
713	II		1.13	1.42		
702	I	G4A	0.46	3.01	0.01	+37%
714	II		0.63	2.90		
703	I	M10C	0.54	3.11	0.01	+46%
715	II		0.79	2.15		
704	I	P1SE	0.33	5.26	0.01	+36%
716	II	+ RL1	0.45	2.15		

apparent change (%) was in the performance of the grosser movements, Reach and Move. The control actions, Grasp and Position showed a lesser degree of apparent change.

It cannot be stated that the two control elements would be performed symmetrically opposite by a clinically normal worker. More emphatically, it could not be stated that these elements were performed in a symmetrically opposite fashion by the hemiparetic subject, for the paretic extremity generally evidenced unnatural, or at least unconventional, movements during control. This should be apparent merely by the nature of the disease.

Hausmanowa-Petrusewicz[67] suggests in her investigations that the unaffected extremity of the hemiparetic is adversely affected by simultaneous work of the symmetrical paralyzed limb. It should be noted that the majority of her investigations were carried out with the two extremities performing simultaneously and symmetrically, but not symmetrically opposite, or mirror image.

Hausmanowa-Petrusewicz's tests were designed to compare rate and strength of squeezing a rubber bulb. The conclusions were (tentatively) that there was an " . . . interference of normal and distorted kinesthetic (space) perception, resembling other types of 'extinction'."

The major difference between the above investigation and Task 2, is that not only is symmetry specified in the empirical "principle," but opposite or mirror image as well. Apparently Hausmanowa-Petrusewicz only considered duplicate or parallel symmetry. Some provisional tests made by the writer show that duplicate control motions of certain types performed by normal industrial workers makes performance more difficult.

MTM practice also recognizes this in synthesizing total task times. For example, a G4A within area of normal vision can be performed simultaneously by the two extremities, but only after practice. G4A cannot be performed simultaneously bilaterally outside the area of normal vision.[68]

The improvement results shown in Table 7 cannot be completely attributed to bilaterial training, for the observations cannot account for the effects of training transfer, motivational shift, fatigue levels, and rhythm. Further, a medically oriented inspection of the actual performance times would be required to make some judgments or absolute conclusions. Therefore, the information is presented as a beginning of a means of documentation of change.

Discussion of Results--Task 3

Task number three was designed to show any possible anomalies in the manual motor character of a brain damaged person with respect to acceleration, velocity, deceleration, and radial differences in motion direction.

The cinema camera described for collecting information was capable of filming at the rate of 128 frames per second, or each frame representing 15×10^{-5} minute. Many angles of positioning the camera, inclusion of strategically placed mirrors, and even simultaneous television monitoring included in the camera field did not produce films that could be analyzed in the vertical plane, horizontal plane, and radial direction simultaneously.

Although the test results produced no quantitative information, better instrumentation will enable studies of this type task to be of some relevance in the analysis and management of the motor character effects of brain damage.

CHAPTER VIII

CONCLUSIONS

The results demonstrate a methodology for objectively comparing motor character in the upper extremity of selected subjects with brain damage as described. Comparisons may be made between the selected subjects and the clinically normal population as well as comparisons of the same subject at desired intervals, or comparisons made for any variety of reasons deemed desirable.

The performance indices reflect a quantified comparison, but for hemiparetic subjects tested, with an implicit combination of quality and quantity of motion. Quality of motion is present in the industrial worker population but is not necessarily documented, since the quality is the range between an acceptable worker and a superior worker.

The overall methodology described and used is well documented and widely understood, although not validated. This permits the performance indices to have consistency as a base for comparison as well as a wide use in many fields.

There exists a minor semantic difference between the Industrial Engineering terminology and clinical words. This minor difference enhances the desirability of a neutral language which may cross many fields; engineering, medicine and allied fields, business, industry, and research.

When simultaneous-symmetrical-opposite tasks were employed, there was an improvement in manual performance. This cannot be entirely attributed to the principle of motion economy used. The motions of position and grasp contained no symmetry or oppositeness. The element Move was opposite and symmetrical within the context of the motion sequence performed.

Collection of suitable time data can be performed by technicians utilizing conventional means. The determination of a specific technique would depend upon the timing device selected.

CHAPTER IX

RECOMMENDATIONS

A. <u>The development of an objective, reproducible system of observing, recording, and evaluating motor learning processes during the pre-threshold phase of learning</u>.

Most studies of learning concern themselves with reinforcement learning, the phase during which the rate of performance is improved. Reinforcement occurs with a stimulus event, in the proper temporal relationship with a response, tending to maintain or increase the strength of a response or of a stimulus-response connection. From the viewpoint of the enterprise, the time interval between the initial attack of a task and the threshold point is arbitrary, although recognized as a point of change. The proportion of this time interval to the total time required to become fully proficient is of little consequence.

It should be noted that all observations made during this investigation began with the first trial after verbal instructions. Although the total number of repetitions was haphazard, it was noted that a simple linear regression analysis produced a slope which demonstrated a very small amount of growth or decay in elemental time. Similar observations made on clinically normal subjects and examined in the same fashion evidenced as many upward trends as downward trends during the pre-threshold phase.

Barnes[69] states his intuitive reactions towards performance improvement are that most of the improvement may be assigned to the correction of fumbles and delays rather than faster movements and better coordination.

From the foregoing it could be concluded that improvement prior to the reinforcement phase of learning would be concerned with how one approaches, analyzes, and initially handles a motor act before establishing his own system of performance. This agrees with the closed-loop feedback cybernetic description of action.[70]

B. The description and documentation of the process of pre-threshold motor learning in the clinically normal human.

Over an extended period, the information collected from recommendation A should be analyzed in order to describe and document the process of pre-threshold learning.

C. The distillation of the basic process of motor learning into a form which can be used to improve motor learning and motor performance in persons with motor difficulties.

When goals A and B have been accomplished, sufficient information will be available to devise procedures (perhaps similar to programmed verbal learning) by which some persons with motor handicaps can be trained to perform a task. By learning to perform the components of that tast, components as microscopic as PDTS elements, persons who could not originally successfully master performance may be able to eventually synthesize a system of total task performance. Perhaps persons with retention difficulties could be drilled in the micro-components until improved retention was achieved.

D. The application of the system developed and the knowledge gained to clinically abnormal situations, i.e., hemiplegia (hemiparesis), Parkinsonism, mental disturbances, etc.

This implementation of knowledge would permit determination of: 1) the nature of the movement disorder, 2) differentiation between the existence of a motor learning deficit and movement disorder per se, 3) the nature of learning deficit.

E. The comparison of the predictive abilities of the system developed with present systems used in determining vocational potential in the vocationally handicapped.

One of the major tasks of our society is the restoration of vocational capacity to individuals who for physical or nonphysical reasons are unemployable. In order to find proper solutions, an adequate evaluation of causes is needed. If a system can be developed (the writer feels that the epicenter of the system is developed in this thesis) which will perform an evaluation in perhaps hours equally as well as present prolonged evaluation systems, the advantages are obvious. Even if the PDTS based system could only predict motor learning/performance capacities, many hours of effort can be saved. Work consists of many ingredients beyond motor skills. If the psycho-social aspects are the prime cause of unemployment it is rather useless to devote half of vocational training time towards motor skill development and vice versa when motor deficits are the problem. The savings in terms of dollars and time could run into the millions for the state and federal agencies dealing with these problems.

F. The establishment of a mutual dialogue with enterprises which could employ handicapped persons.

The large corporations could conceivably engage in in-house matching of a handicapped person's limitations with a tasks demands. Some companies are presently performing large scale projects--with considerable expense. Smaller and more competitive industries are employing the handicapped, but with trial and error matching, or worse, creation of compassionate occupations. These procedures are costly also to the enterprise, but there is a serious risk of causing psychotic trauma to the handicapped individual.

If the system can be sufficiently developed, a rapid means of matching man to task could result, or conversely, matching task to man within bounds. Using the hybrid medico-engineer in consonance with the enterprise, it is likely that the system's vocabulary and thrust will be already understandable to the employer. The use of PDTS has such a wide usage, even the non-users have been exposed to many accounts of its uses--with trade associations, industry groups, trade journals, etc. PDTS may be found in service industries, including banks and hospital administration functions.

APPENDIX

Appendix A. Chronological and Other Data of Predetermined Time System

Name of System	First Applied Date	Publication Containing Information Concerning System	Source of Date	Developed By
Motion-Time Analysis (MTA)	1924	"Motion-Time Analysis" by A.B. Segur, I.E. Handbook, Maynard, McGraw-Hill, New York, 1956	Motion pictures, micromotion analysis, kymograph	A.B. Segur
Body Member Movements	1938	Applied Time and Motion Study, by W.G. Holmes, Ronald Press, New York, 1938	Not known	W.G. Holmes
Motion-Time Data for Assembly Work (Get and Place)	1938	Motion and Time Study, 5th ed., by R. M. Barnes, Wiley, New York, 1963	Time study, motion pictures of factory operations, laboratory studio	Engstrom & Geppinger, General Electric
The Work-Factor System	1938	Work-Factor Time Standards, by Quick, Duncan, & Malcom, McGraw-Hill, New York, 1962	Time study, motion pictures of factory operations, motion study with strobe light	Quick, Shea & Koehler
Elemental Time Standard for Basic Manual Work	1942	"Establishing Time Values by Elementary Motions" by M.G. Schaefer, Proceedings 10th Time & Motion Study Clinic, IMS, Chicago, Now. 1946	Kymograph, motion pictures of factory operations, electric time recorder studies	Western Electric Co.
Methods-Time Measurement (MTM)	1948	Methods-Time Measurement by Maynard, Stegemerten, & Schwab, McGraw-Hill, New York, 1948	Time study, motion pictures of factory operations	Maynard, Stegmerten & Schwab

Appendix A. Chronological and Other Data of Predetermined Time System (Con't.)

Name of System	First Applied Date	Publication Containing Information Concerning System	Source of Date	Developed By
Basic Motion Timestudy (BMT)	1950	Basic Motion Timestudy by Bailey and Presgrave, McGraw-Hill, New York, 1958	Laboratory studies	Presgrave, Bailey & Lowden
Dimensional Motion	1952	Dimensional Motion Times by H.C. Geppinger, Wiley, New York, 1955	Time study, motion pictures, laboratory studies	H.C.Geppinger
Predetermined Human	1952	"Synthesized Standards from Basic Motion Times," Handbook of Industrial Egineering and Management, Ireson & Grant, editors, Prentice-Hall, Englewood Cliffs, N.J. 1955. Also Ph.D. thesis, Purdue University, 1952	Motion pictures of factory operations	I.P. Lazarus

Appendix B. Functions Involved in Subtests: Wechsler Tests.*

Subtest	Functions	Influencing Factors
Information	Long range retention: Association and organization of experience	Cultural environment: Interests
Comprehension	Reasoning with abstractions: Organization of knowledge	Cultural opportunities: Response to reality situations
Arithmetic	Reasoning with abstractions: Concept formation: Retention (of arithmetical processes)	Attention span: Opportunity to acquire the fundamental arithmetical processes
Similarities	Analysis of relationships: Verbal concept formation	A minimum of cultural opportunities
Vocabulary	Language development	Cultural opportunities
Digit Span	Immediate recall: Auditory imagery: Visual imagery at times	Attention span
Picture Arrangement	Visual perception of relationships (visual insight): Synthesis of nonverbal material	A minimum of cultural opportunities: Visual acuity at times
Picture Completion	Visual perception (analysis): Visual imagery	Environmental experience: Visual acuity at times
Object Assembly	Visual perception (synthesis): Visual-motor integration	Rate of motor activity: Precision of motor activity
Block Design	Perception of form: Visual perception (analysis): Visual-motor integration	Rate of motor activity: Minimum of color vision
Digit Symbol	Immediate rote recal: Visual-motor integration: Visual Imagery	Rate of motor activity

*Freeman, Frank S., Theory and Practice of Psychological Testing, New York, Holt Rinehart and Winston, Inc. 1955, pp 163-164.

COPY

PROGRESS NOTES

The patient is a 48-year-old Negro female who had the sudden onset of of a left hemiplegia on 2/26/67. This was not accompanied by unconsciousness or bowel or bladder incontinence, but she did exhibit left facial weakness as well as profound flaccid left hemiplegia. She was admitted to Grady Memorial Hospital and unfortunately we do not have access to the portion of the chart which related to the present illness. As she remained in the hospital she gradually made improvement in return of function in the lower extremity and was seen in the Physical Therapy Department for carrying out range of motion exercises and was thereafter admitted to the Physical Medicine and Rehabilitation Unit for instruction of hemiplegic rehabilitation.

PAST HISTORY: The major problem in the past history has been a persistent hypertension which dates back at least to 1947. During recent years she has been followed by the Medical and Renal Physiology Services and has been maintained on a program of medical management for the hypertension.

PHYSICAL EXAMINATION: On admission the patient is a well developed, well nourished, 48-year-old, Negro female appearing younger than stated age, cooperative and well oriented and with obvious left hemiparesis.

HEAD: Normocephalic.

EYES: The pupils are regular, round and equal; react to light and accommodation. Extra ocular muslces are intact and gross visual testing do not demonstrate any peripheral visual loss.

EARS, NOSE AND THROAT: Clear.

NECK: Supple with full range of motion; no palpably enlarged thyroid or adenopathy. The carotid pulsations are equal bilaterally.

CHEST: Symmetrical with equal expansion and excursion bilaterally. The lungs are clear to percussion and osculation.

HEART: There is a regular sinus rhythm. The left border of cardiac dullness is in the fifth left intercostal space, 2 centimeters outside of the midclavicular line. There is about a grade one atycal systolic murmur with no radiation or thrills noted.

BREASTS: Negative.

ABDOMEN: On plane; there are no masses or tenderness or enlargement of organs.

EXTREMITIES: The extremities on the right are under good voluntary control with normal strength and range of motion. The left upper extremity is under very limited voluntary control with moderate spasticity noted. Passive range of motion can be carried out in all joint segments through full range. There is beginning return in the elbow flexors and only a suggestion of return in the extensors. Attempts to move the shoulder are done by a mass response with no definite return noted in the deltoid although the adductors are intact. There is no evidence of either wrist extension or flexion at this point although there is just a trace of flexion extension of the index finger and the thumb. There are no contractures; there is no pain elicited on carrying out range of motion. The lower extremity shows beginning return in hip flexors and knee flexors as well as in the quadriceps. There is no return noted in the dorsiflexors or plantar flexors of the ankle. The reflexes on the left are hyperactive as compared to the right. There is no Babinski present at this time. Sensation is not noted to be impaired. The facial weakness has almost completely recovered.

DIAGNOSIS: Left hemiparesis as a result of right CVA involving the right middle cerebral artery distribution.

PROGNOSIS: The prognosis for practical ambulation is very good considering the degree of return which has occurred at this early date. The prognosis for recovery in the left upper extremity is guarded although with beginning return occurring this may later be utilized as an assistive hand if more complete recovery does not occur.

DISCUSSION: This patient's blood pressure on admission was 148/80 and it is understood from the medical service that there is no reason to delay intensive rehabilitation program. It is also understood that she is to be followed from the medical standpoint by that service for control of the hypertension. She may be begun on the tilt table to gradually bring her to the orthograde position as well as sitting to increase her sitting tolerance. She may be started on the mat to develop sitting balance and should undergo strengthening exercises of the extremities on the right. When she has successfully stood without any hypotensive symptoms she may be begun with standing in the parallel bars utilizing the knee cage and dorsiflexion assistance device and progress to standing balancing and ambulation. She should also be seen by the occupational therapist for evaluation and instruction in ADL activities as well as continual follow-up to carry out one handed activities as well as to gradually take advantage of return as it occurs in the left upper extremity. She may very well require bracing in the future of the left lower extremity but this will be delayed until sufficient time has been given to trial bracing in her ambulation activities to determine whether the brace is necessary and if so the specific type necessary. She appears to be bright and highly motivated and it is felt that she will continue to make rapid progress utilizing the recovery that is occurring.

3-17-67 Physical Therapy Initial Note

______was admitted to the Physical Medicine and Rehabilitation in-patient nursing area 3-15-67 for a hemiplegic rehabilitation program. On admission, she did not have any equipment.

On initial evaluation, she had normal ROM in all four extremities. Both her right upper and lower extremities exhibited normal strength. Her left upper extremity showed beginning return in all muscle groups; however, none of them could function anti-gravity. Her left lower extremity was functional in the hip and knee, but there was no movement noted at the ankle.

She could transfer independently from the wheelchair to the bed and toilet, but required some assistance for bathtub, shower, and floor transfers.

Her twice daily physical therapy program will consist of:

1) ROM left upper extremity and left lower extremity
2) strengthen left upper extremity and left lower extremity
3) transfer techniques
4) ambulation

3-22-67 Occupational Therapy

______was admitted to the PM&R Nursing Area 3/15/67. She was referred to OT for a hemiplegic rehabilitation program consisting of:

1) ADL evaluation and training
2) ROM exercises and muscle re-education
3) Homemaking activities and possible pre-vocational exploration.

Initial interview and evaluation reveal 0-110° active flexion at the left elbow against gravity. No active left wrist motion noted with a possible trace of the first and second finger intrensics. Passive ROM full range with no pain noted.

She has previously received OT and was independent in dressing including bra.

Prior to her admission she was employed as an aide in the GMH stroke clinic from Nov., 1966. She is also interested in sewing and dress-making and states she does a great deal of this for friends.

Attitude towards the rehabilitation program appears to be good. She will be seen in OT once daily for:

1) ADL training
2) Refinement of one-handed skills
3) Prevocational activities and homemaking skills.

4/11/67

This patient has done well from a medical standpoint, is able to ambulate quite effectively and is beginning to show some return of both extension and flexion in the fingers. There is a suggestion of return in the triceps and the deltoids as well. She is having moderate swelling of the hand and for this reason has been instructed to use a sling during all of her walking and sitting activities. There is no evidence of subluxation at the shoulder or of any painful symptoms suggestive of a shoulder hand syndrome. She has had a small feruncle on the right long finger and also over the medial aspect of the left knee and has placed on Tegopen for this.

4/18/67

The patient's blood pressure has remained quite stable in the 120-160/110 range and she has been completely asymptomatic. She has been doing well in her program and is able to demonstrate beginning return in the triceps against gravity and shows very excellent endurance in all walking activities and is showing recovery of all musculature about the ankle.

4/25/67

This patient continues to make good progress in both the left lower and upper extremity, has regained much strength about the shoulder girdle especially in the middle and posterior deltoids as well as the scapular adductors, is able to activate both triceps and biceps as well as wrist extensors and beginning finger extensors as well as the flexors which have been present for some time. Her ambulation is much better than it was and it would appear that she will not require any lower extremity bracing as she has a good strong quadriceps and can activite both peroneals and anterior tibials. She continues to use the sling for the upper extremity during periods outside of treatment due to the edema of the hand which was developing. She has had no medical problems and her blood pressure is remaining stable in a good safe range.

5/2/67

This patient has continued to have improvement in recovery of function of the left upper extremity and is walking with a Lofstrand crutch without difficulty. We will explore the possibility of carrying out some pre-vocational activities during the coming weeks. We would suggest that she have her time extended for hospitalization for an additional 30 days.

5/9/67

She has continued to exhibit increased return in voluntary function at the shoulder and biceps and triceps and has made great improvement in wrist and finger extensors and flexors. We will contact Dr. Tuttle to determine whether she can possibly return to his employment on a work evaluation basis of one day weekly during the remainder of her hospitalization. It is felt that she would be able to carry out some of her former responsibilities of preparing patients for physical examinations, weighing, tem. taking, etc. She should also have her own Lofstrand crutch ordered.

5/23/67

This pt. continues to show return in the left upper ext. and is gaining both flexion and extension of the fingers and wrist and is now able to lift 5 lb. weights with the left hand. Her ambulation is safe and really very good and for this reason we would like to have her remain with us for several additional weeks to take full advantage of the improvement that is taking place. It is still hoped that following her discharge from the unit that she will be able to return to at least part time work at her former job.

5/30/67

This young lady continues to make such remarkable improvement in recovery of the upper extremity that we would like her to remain an additional 30 days. She has regained quite good grip in the hand, is recovering in the pronation and supination and her gait patterns are quite good.

6/6/67

She has had no medical problems. Her blood pressure has remained quite stable and although she was somewhat discontent to stay here for continued treatments several weeks ago, she herself is aware of the good recovery of function and is anxious to remain as long as progress is being made.

Date 7/22/68

Initial or Follow-up Exam

(Name) ———, J. H. Sex M

(Age) 45 (Birthdate) 4/31/23 (Handedness) R

(Side of Hemiplegia) L (Date of Onset) 6/6/68

(Diagnosis) (HAD MILD (R) CVA IN 1964) - MINIMAL RESIDUAL

(Other Diagnosis)

Work History: (UE function) DROVE TRUCK

Hobby: (UE function) NONE

Skills: (i.e. piano, guitar, typing) NONE

I. Aphasia Screening:

Can (not) identify:
- a) coin ✓
- b) pen ✓
- c) key ✓
- d) parts of watch ✓

Follows simple commands:
- a) point to door ✓
- b) point to window ✓
- c) point to bed ✓

II. Visual Screening:
- a) peripheral fields to confrontation ✓
- b) peripheral fields to bilateral ✓ simultaneous stimulation ✓

III. Sensation (UE):

A. Touch: (Single Stimulus) Response: 1) Exact 2) General 3) None 4) Other

Right Side :	Shoulder:	1
Left Side :		1
Simultaneous:		1
Right Side :	Elbow :	1
Left Side :		1
Simultaneous:		1
Right Side :	Wrist :	1
Left Side :		1
Simultaneous:		1
Right Side :	Middle fingertip:	1
Left Side :		1
Simultaneous:		1

B. <u>Position Sense</u> (UE): Response: 1) Exact 2) Hesitant 3) Errors

Right Side:	Shoulder:	1
Left Side::		1
Right Side:	Elbow :	1
Left Side :		1
Right Side:	Wrist :	1
Left Side :		1
Right Side:	Middle Finger:	1
Left Side :		1

IV. <u>Stereognosis</u> (UE): _

Identify:		Left	Right
a)	coin	✓	✓
b)	key	✓	✓
c)	pen	✓	✓

V. <u>Neglect</u> (Denial): Response: 1) Unable 2) Accurate 3) Proximity 4) Ipsilateral

Ask to point to:

a)	shoulder	2
b)	elbow	2
c)	wrist	2
d)	hand	2

If unable, ask to distinguish his hand from yours:

VI. <u>Motor Function</u>:

A. <u>Reflexes</u>: (0 to +4)

	Left	Right
Triceps	+3	+2
Biceps	+4	+3
B - R	+4	+3
Finger Flexar (Hoffman's)	+3	+2

B. <u>Spasticity</u> (Resistance to passive movement) Response: Increased Decreased Normal

	Left	Right
Triceps	N	N
Biceps	I	
Shoulder Adductors	I	
Shoulder Adductors	N	
Pronators	I	
Supinators	N	
Wrist Flexors	I	
Wrist Extensors	N	
Finger Flexors	N	
Finger Extensors	I	

C. Voluntary Control:

	Left	Right	Response: Yes / No / Partial
Abduct shoulder	PARTIAL		
Horiz., Adduct shoulder	YES		
Internal rotation shoulder	YES		
External rotation shoulder	NO		
Elbow flexion	YES		
Elbow extension			
Supination			
Pronation			
Wrist flexion			
Wrist extension	PARTIAL		
Finger flexion (mass)	YES		
Finger extension (mass)			
Thumb to 1st finger			
Thumb to 2nd finger			
Thumb to 3rd finger			
Thumb to 4th finger			

Tapping rate:
L < R
L = R
L R
Unable L R

Mass reflex movement:
Describe; FLEXION OF ELBOW TO TOUCH ACROMIUM — REQUIRES ABDUCTION. IF ELBOW AT SIDE, ADDUCTS FOREARM IN FLEXING

ROM- Passive

	±90°	±45°	±15°	None
Abduction				
Left	✓			
Right	✓			
Ext. Rotation				
Left		< 60°		
Right	✓			
Supination				
Left	✓			
Right	✓			
Wrist Extension				
Left	✓			
Right	✓			

Finger Extension:	±0°	±30°	±60°	None
Left	✓			
Right	✓			

Finger Flexors:	tips to palm	±1/2"	±1"	More
Left	✓			
Right	✓			

Elbow Extension:	±0°	±30°	±60°	None
	✓			

Elbow Flexion:	tip to shoulder	1/2"	1"	More
Left	✓			
Right	✓			

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Buros, Oscar K., ed., Mental Measurement Yearbook, Highland Park, N. J., 6th ed., Gryphon Press, 1965, p. 1081.

2. Chyatte, S. B., Demonstration, 1968, Emory University School of Medicine, Department of Physical Medicine.

3. Regenos, Eleanor B., Demonstration,1968, Grady Memorial Hospital, Department of Physical Medicine.

4. Gordon, S. C., Jr., Demonstration, 1967, Atlanta Employment Evaluation and Service Center, State Department of Education.

5. Stedman's Medical Dictionary, 21st ed., Baltimore, The Williams and Wilkins Co., 1966, p. 459.

6. Krick, E. V., Methods Engineering, New York, John Wiley & Sons, Inc., 1962, p. 212.

7. Journal of Industrial Engineering, Nov.-Dec. 1965, pp. TM 12-22.

8. Karger, D. W., and Bayha, F. W., Engineered Work Measurement, New York, Industrial Press Inc., 2nd ed., 1965, p. 35.

9. Taylor, F. W., Subcommittee on Administration of the ASME, "The Present State of the Art of Industrial Management," Transactions of the ASME, 34, p. 1200.

10. Taylor, F. W., Scientific Management, New York, Harper & Row, 1911, p. 125.

11. Gilbreth, F. B., Applied Motion Study, New York, Sturgis and Walton Co., 1917, adapted from.

12. Merrill, H. F., ed., Classics in Management, New York, American Management Association, 1960, p. 280.

13. Segur, A. B., Manufacturing Industry, 1927.

14. Maynard, H. B., ed., Handbook of Industrial Engineering, New York, McGraw-Hill, 1956, Sec. 5, p. 108.

15. Ibid., Sec. 5, p. 109.

16. Quick, J. H., Duncan, J. H., and Malcom, J. A., Jr., Work-Factor Time Standards, New York, McGraw-Hill, 1962, adapted from.

17. Maynard, op. cit., Sec. 5, p. 43.

18. Maynard, loc. cit.

19. Maynard, H. B., Stegemerten, G. L., and Schwab, J. L., Methods-Time Measurement, New York, McGraw-Hill, 1948.

20. Bailey, G. B., and Presgrave, R., Basic Motion Timestudy, New York, McGraw-Hill Co., 1958.

21. Karger, op. cit., p. 43.

22. Abruzzi, Adam, Work Measurement, Columbia University Press, New York, 1952, Ch. 12.

23. Buffa, E. S., "The additivity of Universal Standard Data Elements," Journal of Industrial Engineering, Vol. VII, No. 5 (Sept.-Oct. 1956),

24. Davidson, H. O., Functions and Bases of Time Standards, American Institute of Industrial Engineers', 1952, p. 140.

25. Ghisselli, E. E., and Brown, C. W., Personnel and Industrial Psychology, McGraw-Hill, New York, 1948, p. 270.

26. Gomberg, W., "Union Problems in Setting Production Standards," Paper Delivered Before the Institute of Industrial Relations, University of California, Berkeley, 1950.

27. Nadler, G., "Critical Analysis of Pre-determined Motion Time Systems," Proceedings of the National Time and Motion Study and Management Clinic, 1952, p. 28.

28. Reuther, W. P., Inter-Office Communication, 1949.

29. AFL-CIO, "Resolution of Industrial Engineering," adopted by the Fourth Constitutional Convention on December 12, 1961.

30. Krick, E. V., op. cit., p. 370, adapted from.

31. Freeman, F. S., Theory and Practice of Psychological Testing, New York, Holt, Rinehart and Winston, Inc., 1955, pp. 163-164.

32. Freeman, F. S., op. cit., p. 170.

33. Eyman, R. K., Dingman, H. F., and Windle, C., "Manipulative Dexterity and Movement History of Mental Defectives," Perceptual and Motor Skills, 1959, Vol. 9, 291-4.

34. Distefano, M. K., Jr., Ellis, N. R., and Sloan, W., "Motor Proficiency in Mental Defectives," Perceptual and Motor Skills, 1958, Vol. 8, 231-234.

35. Hancock, W. M., and Foulke, J. A., "Learning Curve Research on Short-Cycle Operations," Report 112, The MTM Association for Standards and Research, Ann Arbor, Mich., 1963.

36. Raphael, D. L., and Clapper, G. C., "A Study of Simultaneous Motions, Report 105, The MTM Association for Standards and Research, Ann Arbor, Mich., 1952.

37. Hancock, W. M., and Foulke, J. A., Personal Discussions, April, 1968.

38. Fitts, P. M., and Peterson, J. R., "Information Capacity of Discrete Motor Responses," Journal of Applied Psychology, Vol. 67, No. 2, February, 1964.

39. Hancock, op. cit.

40. Karger, op. cit., pp. 125-129.

41. Krick, op. cit., p. 150.

42. Hancock, W. M., and Foulke, J. A., Personal Discussions, April, 1968.

43. Hancock, op. cit.

44. Foulke, Telephone Conversation, January, 1968.

45. Karger, op. cit., p. 235.

46. MTM Data Card, Copyright 1965, MTM Association for Standards and Research, Ann Arbor, Mich.

47. Karger, op. cit., p. 248.

48. Ibid., p. 229.

49. Ibid., p. 230.

50. MTM Data Card, op. cit.

51. Bard, G., and Hirschberg, G. G., "Recovery of Voluntary Motion in Upper Extremity Following Hemiplegia," Archives of Physical Medicine, Vol. 46, 1965, p. 567, adapted from.

52. Karger, op. cit., p. 134.

53. Ibid., p. 141.

54. Ibid., p. 139.

55. Ibid., p. 140.

56. Schwab, J. L., Personal Discussions and Correspondence, 1967.

57. Karger, op. cit., p. 209.

58. Poock, G. K., "Prediction of Elemental Motion Performance Using Personnel Selection Tests," Unpublished Doctoral Dissertation, University of Michigan, Ann Arbor, 1967, p. 17.

59. Ibid., p. 89.

60. Denny-Brown, D., Journal of Nervous and Mental Diseases, 112, 1; London, 1950, adapted from.

61. Twitchell, T. E., "The Restoration of Motor Function Following Hemiplegia in Man," Brain, Vol. 74, 1957, p. 31.

62. Ibid., p. 35.

63. Karger, op. cit., p. 107.

64. Ibid., p. 111.

65. Barnes, R. E., Motion and Timestudy, 5th ed., John Wiley and Sons, New York, 1963, p. 220.

66. Ibid., p. 222.

67. Hausmanowa-Petrusewicz, Irena, "Interaction in Simultaneous Motor Functions, American Medical Association Archives of Neurology and Psychiatry, Vol. 81, 1959, p. 57-173.

68. MTM Data Card, op. cit.

69. Barnes, R. M., "An Investigation of Some Hand Motions Used in Factory Work," University of Iowa Studies in Engineering, Bulletin 6, 1936.

70. Smith, K. U., and Henry, P. H., "Cybernetic Foundations for Rehabilitation," Proceedings: NUSTEP, American Journal of Physical Medicine, Vol. 46, No. 1, 1967, p. 438.